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THESIS

AN ANALYSIS OF HARDWARE REQUIREMENTS FOR
AIRBORNE TACTICAL MESH NETWORKING NODES

by

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March 2005

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Wireless mesh mobile ad hoc networks (MANETs) provide the military with the opportunity to spread information superiority to the tactical battlespace in support of network-centric warfare (NCW). These mesh networks provide the tactical networking framework for providing improved situational awareness through ubiquitous sharing of information including remote sensor and targeting data. The Naval Postgraduate School's Tactical Network Topology (TNT) project sponsored by US Special Operations Command seeks to adapt commercial off the shelf (COTS) information technology for use in military operational environments. These TNT experiments rely on a variety of airborne nodes including tethered balloon and UAVs such as the Tern to provide reachback from nodes on the ground to the Tactical Operations Center (TOC) as well as to simulate the information and traffic streams expected from UAVs conducting surveillance missions and fixed persistent sensor nodes. Airborne mesh nodes have unique requirements that can be implemented with COTS technology including single board computers and compact flash.

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AN ANALYSIS OF TACTICAL MESH NETWORKING HARDWARE
REQUIREMENTS FOR AIRBORNE MOBILE NODES

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ABSTRACT

Wireless mesh mobile ad hoc networks (MANETs) provide the military with the opportunity to spread information superiority to the tactical battlespace in support of network-centric warfare (NCW). These mesh networks provide the tactical networking framework for providing improved situational awareness through ubiquitous sharing of information including remote sensor and targeting data. The Naval Postgraduate School's Tactical Network Topology (TNT) project sponsored by US Special Operations Command seeks to adapt commercial off the shelf (COTS) information technology for use in military operational environments. These TNT experiments rely on a variety of airborne nodes including tethered balloon and UAVs such as the Tern to provide reachback from nodes on the ground to the Tactical Operations Center (TOC) as well as to simulate the information and traffic streams expected from UAVs conducting surveillance missions and fixed persistent sensor nodes. Airborne mesh nodes have unique requirements that can be implemented with COTS technology including single board computers and compact flash.

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I.   INTRODUCTION

A.   BACKGROUND

Information technology advances, particularly in the area of networking, are drastically reshaping daily life and have provided a catalyst for transformation in the United States military. These technologies have already had a major impact on the planning and conduct of operations ranging from combat to post-hostilities in both Operations Enduring Freedom and Iraqi Freedom as well as military operations other than war (MOOTW) such as recent tsunami relief efforts in South-East Asia. The military is determined to continue rapidly incorporating available information technologies and adapting organizations to maximize the value of these technologies under the auspice of Network-Centric Warfare (NCW) theory and its underlying architectural framework, the Global Information Grid (GIG), and more specifically FORCEnet within the Navy and Marine Corps. The Office of Force Transformation describes these technologies as a force enabler and succinctly states the case for the benefit they afford:

> As a new source of power, NCW has a profound impact on the planning and conduct of war by allowing forces to increase the pace and quality of decision making, in effect changing the rules and pace of military operations. A warfighting force with networked capabilities allows a commander to more quickly develop situational awareness and understanding, rapidly communicate critical information to friendly combat forces, and marshal the appropriate capabilities to exert massed effects against an adversary.[1]

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[1] Department of Defense, Office of Force Transformation, *The Implementation of Network-Centric Warfare* (Washington, D.C., 2005), 18.

The current emphasis on force transformation to support NCW coupled with the push for both "jointness" amongst the services and use of commercial off the shelf (COTS) equipment is revolutionizing tactical military communications. The information grid must support interoperability amongst not only the services but also with outside agencies such as the Department of Homeland Security, non-governmental organizations such as the Red Cross and foreign allies in unfamiliar operational environments all while being both rapidly deployable and expandable. The grid will have to support interfaces with personal computers, communication systems, weapons systems, and sensors in an inter-networked environment. Internet protocol (IP) based communications provide the mature, robust foundation for integrating the components of the GIG. Ever increasing communication flows and the growing reliance on them mandate an increased effort to field cost-effective, rapidly deployable and robust networking platforms.

Commercially available and relatively inexpensive equipment such as those which comply with the specifications of the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards, commercially marketed as Wi-Fi (wireless fidelity), has made connectivity ubiquitous from wireless home networks to public and municipal hotspots in coffee shops, universities and airports. Wireless broadband technologies also provide the military with exciting opportunities. Wireless networks afford infrastructure cost savings both during initial installation and when expanding service not to mention the reclaimed space they afford by eliminating

wiring (also a potential fire hazard aboard ships and submarines where space is always at a premium). However the greatest promise of wireless broadband technologies for the military is the ability to extend IP networks which have historically been relegated to ship and shore installations to rapidly deployable units anywhere in the battlespace.

B.   MOBILE AD HOC WIRELESS MESH NETWORKS

Networks conforming to the 802.11 Wi-Fi standards can operate in two modes: ad hoc and infrastructure. In ad hoc mode, wireless nodes can communicate point-to-point to other wireless nodes within immediate radio range. These networks can be quickly established almost anyplace with nothing more than a computing device and 802.11 network adapter. Infrastructure mode requires special nodes called access points (APs) which connect to the existing network and interact with both the wired network and wireless nodes within their immediate range (Fig. 1). The wired local area network (LAN), typically an Ethernet, provides the backhaul for connectivity to some wide area network (WAN) such as the Internet or, in the military context, the GIG.

A number of mechanisms exist, however, that enable multi-hop radio relay of communications within mobile ad hoc wireless networks (MANETs) without the support of any fixed infrastructure. In contrast to the purely point-to-point ad hoc wireless networks discussed earlier, here every node essentially acts as not only a host for the transmission or termination of network traffic but also a network router for other nodes within the MANET. In these mesh networks, routing and resource management are

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distributed amongst all nodes which then coordinate communication amongst themselves.
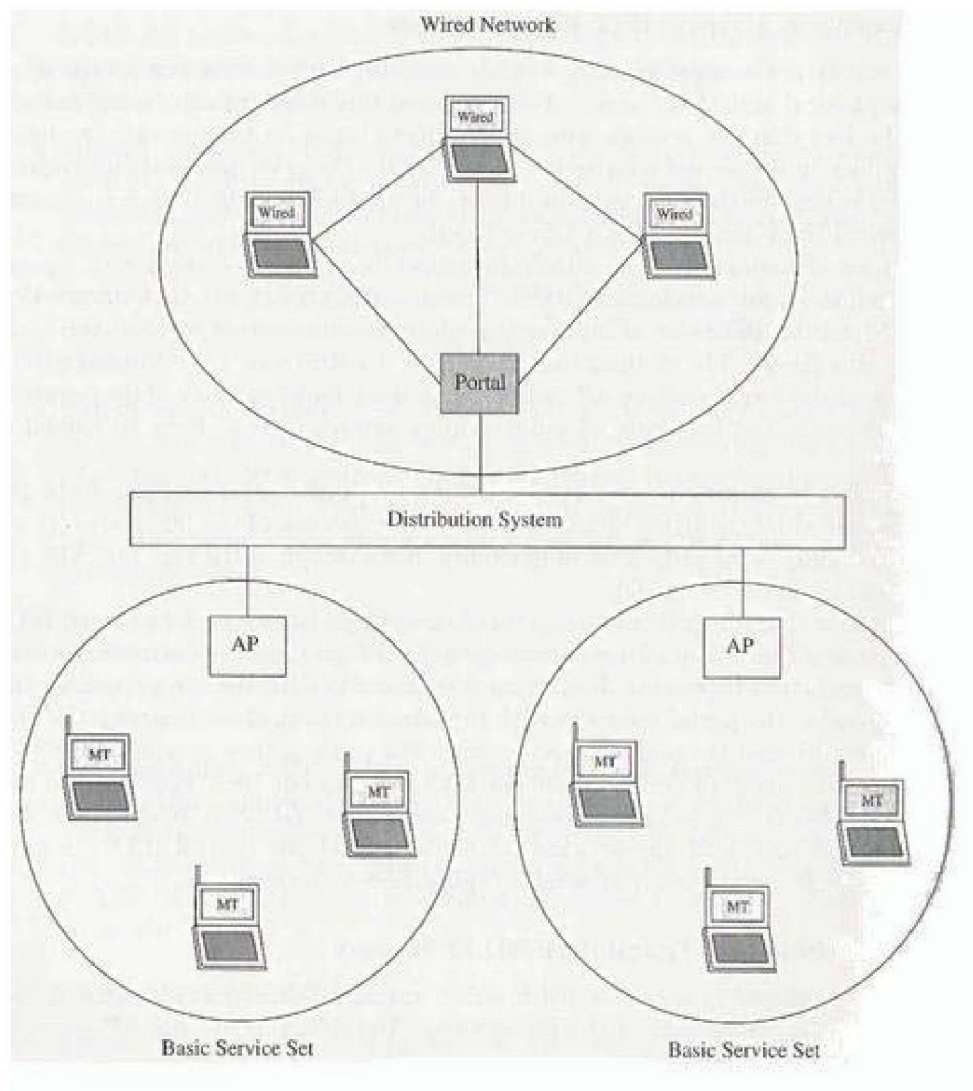
Figure 1. Wireless infrastructure networks connected to wired network through access points[2]

Mesh networking boasts provisions for many of the requirements that a military environment necessitates. They can be set up quickly, are reliable, and support multicast routing. Mesh networks can be quickly established because they are self-forming. Nodes using the

2 C. Siva Ram Murthy and B. S. Manoj, *Ad Hoc Wireless Networks* (Upper Saddle River, NJ: Prentice Hall, 2004), 68.

appropriate mesh routing protocols will discover other nodes similarly enabled within radio range and organize route tables based on the neighbors in the immediate vicinity while exchanging this information with other nodes. As the mesh organizes itself in this way, nodes become aware of distant nodes through their neighbors.

Mesh networks are also self-healing which provides for network reliability. Since routing and resource management are distributed throughout the nodes, there is no single point of failure. If links are degraded or nodes are lost, the mesh simply finds a different route to pass network traffic (Fig. 2). Additionally, as more nodes are added, the numbers of routes increase making the mesh more robust.
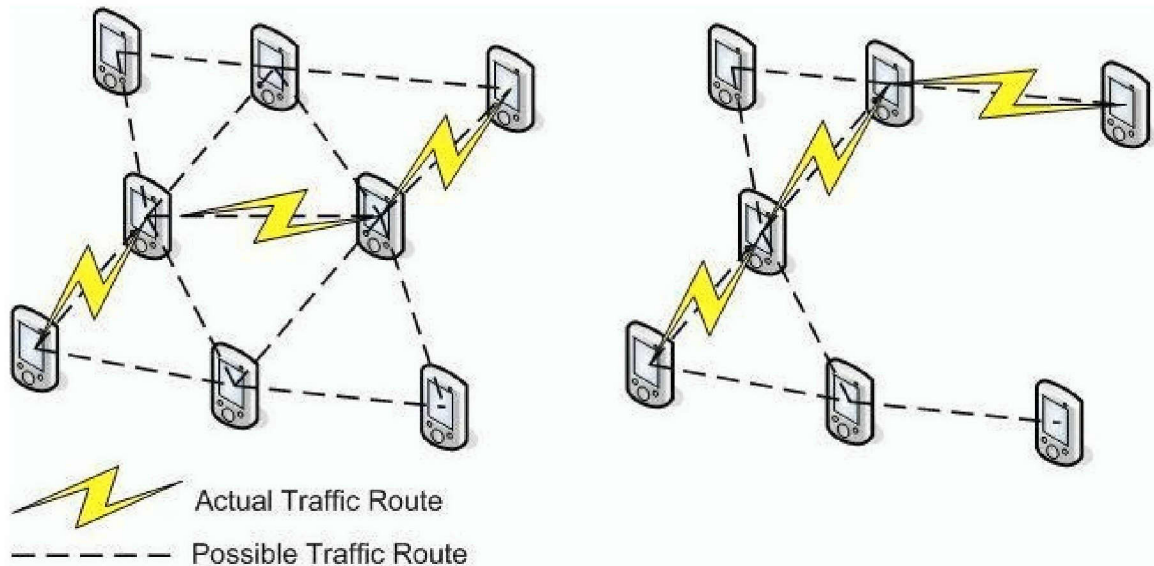
Figure 2. Mesh network adjusts routing for lost node

Finally, mesh networks are packet switched and can share IP traffic including multicast. Their reliance on the IP stack at the network layer means that mesh network clusters can integrate into the GIG through join points which serve essentially the same purpose as access points. Mobile meshes can then provide a reliable conduit for

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sharing real-time multicast traffic such as reconnaissance video from unmanned aerial vehicles (UAVs) or the transmission of marching orders from a Tactical Operations Center (TOC) to ground units dispersed throughout the mesh.

C.   TACTICAL NETWORK TOPOLOGY

The Naval Postgraduate School's Tactical Network Topology (TNT) project, formerly the Surveillance and Target Acquisition Network (STAN), sponsored by US Special Operations Command (USSOCOM), explores the application of a variety of current commercial information technologies by experimenting with them in a military environment and attempting to demonstrate their possible integration into the GIG. The objective is the development of a replicable and deployable network model which increases combat effectiveness and situational awareness by providing stand-off tools for detecting and fixing enemy positions while mitigating the possibility for fratricide. The goal is to provide wireless mobile communications between soldiers, tactical vehicles and aircraft with standardized, commercially available plug and play technologies adapted for military use.
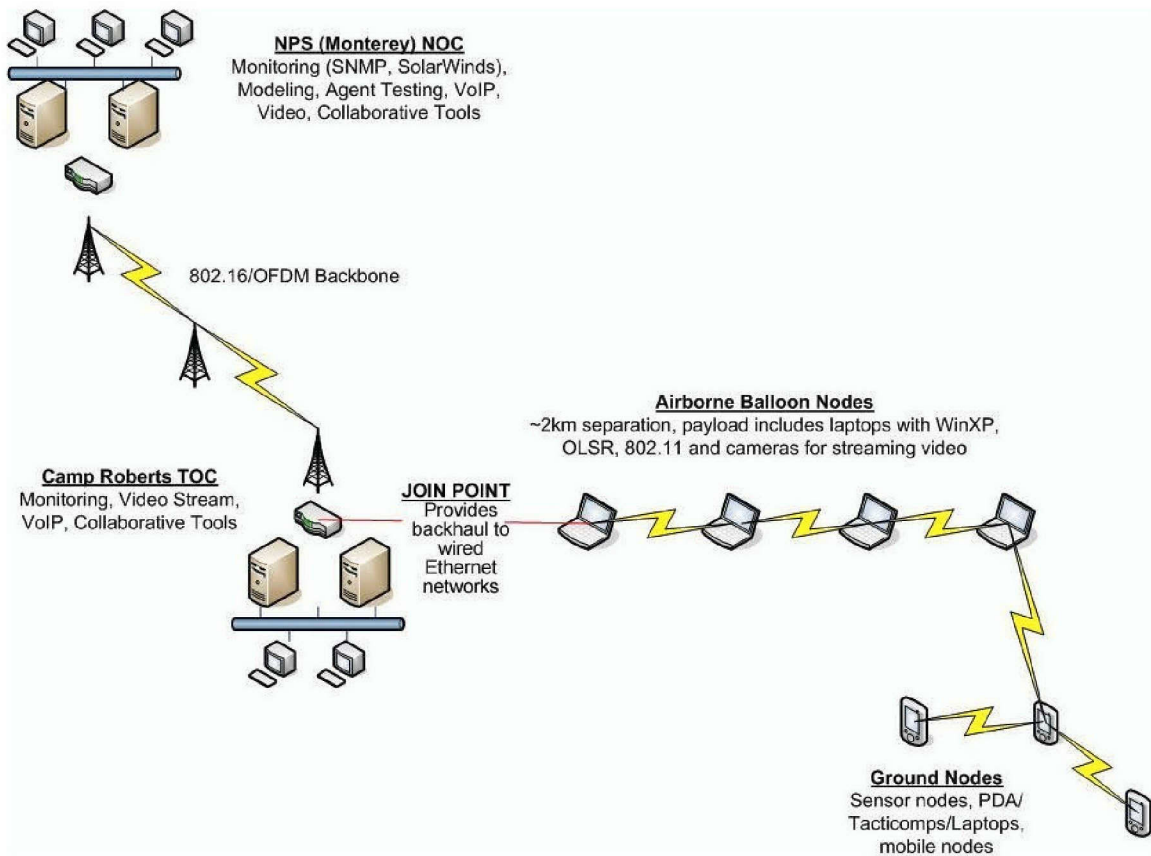
Figure 3.   TNT Network Diagram

The TNT project focuses on integration of technologies and emphasizes adaptability to avoid the stovepipe issues faced by the vast majority of legacy command and control systems and particularly military sensor systems. A large portion of TNT is focused on developing meshed sensor clusters that provide information to the warfighter through a variety of alerts including full motion video. These remote sensors play a major role in the development of situational awareness tools. They also fulfill a second, equally important function by creating a traffic load with their data streams that enables network monitoring under expected operational conditions and facilitates the increased understanding of the network's dynamics.

D. AIRBORNE MESH NODES

The mesh nodes within the TNT network are a mix of ground based and airborne nodes, both stationary and mobile. The stationary airborne nodes are tethered balloons (more accurately, they are moored[3]), roughly ten feet in diameter and raised to a height of 500-1000 feet above ground level (AGL) (Fig. 4). These balloons not only provide reachback to the ground nodes beneath them but also provide persistent surveillance in a manner that could be adapted for future use in activities such as border security.

Figure 4. Preparations to launch balloon node

Mobile manned aircraft include the Pelican, a modified Cessna 337 Skymaster long-endurance aircraft with a UAV-based optical imaging system payload[4] and the A-170 airship.

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[3] Department of Transportation, Federal Aviation Administration, Balloon Flying Handbook (Washington, D.C., 2001), 57.

[4] Naval Postgraduate School, "NPS/CIRPAS Activity Summary," 03 Feb 2005, <http://web.nps.navy.mil/~cirpas/Projects/FBE-H Activity Summary.html>.

The Pelican is provided by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS), a Naval Postgraduate School research center, and acts as a surrogate for the Predator UAV for TNT scenarios. The A-170 is a 178 foot long free-flying blimp equipped to operate as a mobile aerial reconnaissance platform.

The other mobile aircraft is the Tern UAV (Fig. 5) manufactured by BAI Aerosystems, Inc. The Tern is a compact, versatile tactical UAV. It is an easily deployable, cost effective way to perform aerial remote sensing. The Tern is used not only to provide streaming video of remote events, but also to provide the critical function in testing the self-forming and self-healing properties of the mesh by flying in and out of the network to test traffic load balancing and network organization.

Figure 5. Tern multi-purpose UAV[5]

The wireless airborne nodes provide a major portion of the wireless mesh network fielded during TNT experiments. Their role is crucial not only in simulating the video streams that UAVs and persistent surveillance nodes would

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[5] BAI Aerosystems, Inc., "Tern: Small Tactical UAV System," 18 Feb 2005, <http://www.baiaerosystems.com/tern.html>.

provide in an operational environment but also for providing data on mesh network capabilities when resources are stretched to long distances or mobile at high speeds.

The payloads that provide the computing capabilities were created with a combination of readily available COTS equipment modified to fit the physical constraints imposed by their intended usage. However, once placed in the TNT environment under normal operating conditions, it became apparent that modifications to the payloads would be required in order to maximize their effectiveness.
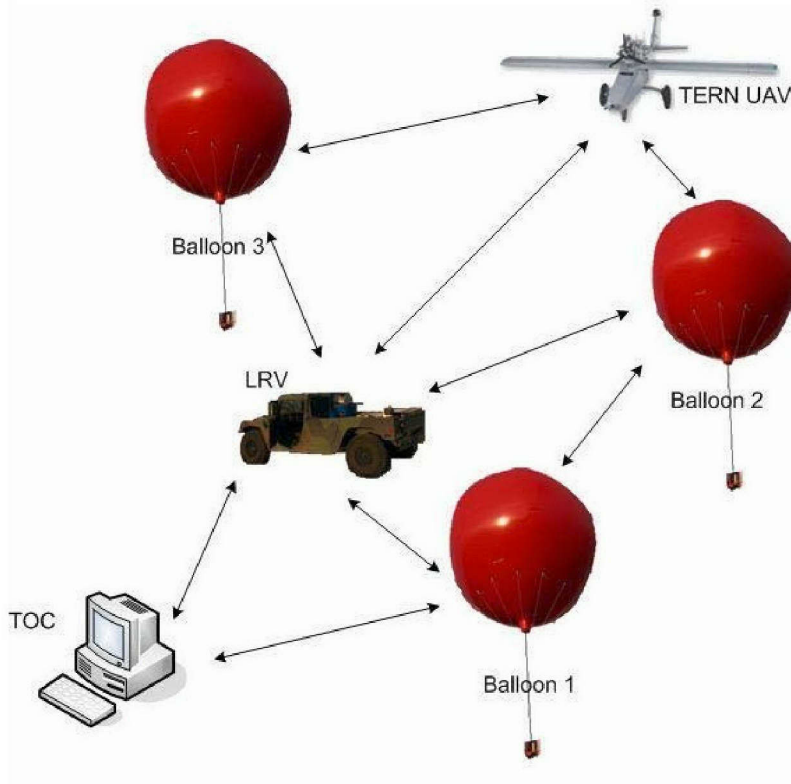
Figure 6. TNT mesh connectivity design

E. SCOPE

The purpose of this thesis is to provide analysis of the data collected during TNT-1 related to the operation of the airborne mesh network. The results from that data are used to draw conclusions on the design of the airborne

payloads. The thesis will detail the improvements made to the payloads in preparation for TNT-2 and the accompanying results. Finally, recommendations are made for both the next generation of airborne mesh nodes and follow on research opportunities.

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II. TACTICAL NETWORK TOPOLOGY

A. BACKGROUND

The TNT-1 experiments sought to measure mesh network performance by observing the impact of several variables on node performance including distance between nodes, network load, and mobility. The nodes included multiple airborne and ground nodes, both stationary and mobile (at various speeds), to test not only various performance measures monitored primarily at layers two and three of the OSI stack, but also to test the self-forming/self-healing properties of mesh networks.

All nodes were standardized in that they ran the Windows XP Professional operating system with the Optimal Link State Routing (OLSR) mesh routing protocol over Proxim ORiNOCO 802.11a/b/g ComboCard wireless Ethernet adaptors. The outputs of the wireless cards were amplified to one watt to increase range. Airborne nodes were also equipped with video cameras which provided the bulk of the traffic flow for network performance observation. The nodes streamed their feed via a Pelco digitizer.

Tests involved three tethered balloon nodes raised to approximately 1000 feet AGL stretched out in a roughly linear formation with 1-2 kilometers between them. Two ground mobile nodes consisting of similarly equipped laptops minus the camera and digitizer were transported in HMMWVs. Mobile airborne payloads were flown aboard an A-170 airship and the Tern. Finally, a laptop node was used as a join point to the wired network in the TOC.
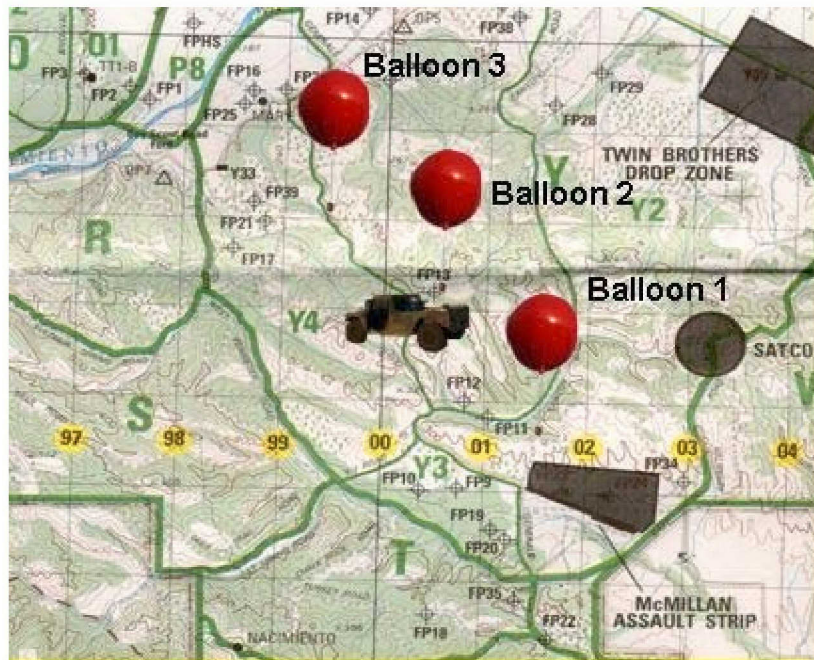
Figure 7. Camp Roberts TNT-1 overview

NOTE: Balloon positions are approximate; TOC is located adjacent the McMillan Assault Strip

The TOC included stations for monitoring application layer flow (including the SA Agent application developed by NPS which includes tools for geo-locating, surveillance alerts, chat and video streams) as well as network layer performance (via Solar Winds network monitoring software) and data link layer performance (via Air Magnet and AiroPeek wireless link layer monitoring tools). Tests involved raising the tethered balloons and monitoring the network traffic from the TOC while attempting to station the ground nodes in areas which would test the mesh's ability to self-form and organize to improve overall network performance. Mobile airborne nodes were flown in to see their impact on network performance and their ability to join the mesh at high speeds.

Attempts were also made to integrate Rajant Corporation's BreadCrumb devices. These units are self-

contained, battery operated devices that when powered discover other BreadCrumb devices and form a mesh network which other 802.11b devices can then join. The product seems to be a capable alternative as a join point to the laptops currently in use which uses software to bridge the wireless and wired interfaces.

B.   OBSERVATIONS AT LAYER THREE

The average data rate of the tethered balloons in a static environment was approximately 4.3kbps in and 1.3kbps out. This performance was considerably better than that of the mobile ground nodes which is consistent with the notion that 802.11 networks are not particularly suited to mobile platforms.

The Tern and A-170 nodes had few recorded observations in terms of data rate. The low number of observations is based purely on their limited on station time during the experiments. However, their data rates closely matched those of the tethered balloon nodes despite being mobile when in use. Finally, the TOC join point mesh node had nearly three times the average input and seven times the average output data rates of the air nodes with approximately 9.9kbps in and 9.8kbps out. This is due to the fact that although the join point was a node on the edge of the network in a more stable environment and did not have to negotiate contact with other neighbor mesh nodes to the extent of the remaining nodes it was a bottleneck in passing all traffic between the wireless and wired networks.

C. MOBILITY AND SELF-FORMING/SELF-HEALING CAPABILITY

As expected, the addition of nodes strengthened the network, making it more robust and more reliable. During experiments with the A-170 airship, the entire network had improved performance in terms of both stability and data rate almost immediately upon the introduction of the new node. The A-170 was able to join the mesh from approximately two kilometers away from the TOC and remained connected despite its mobility as it flew a zigzag through the line of tethered balloons and then took turns encircling each of them (Fig. 8). The data rate the nodes experienced at this point was very close to the average during other experiments except with increased input data rates to approximately 5.5kbps for the balloons (Fig. 9).
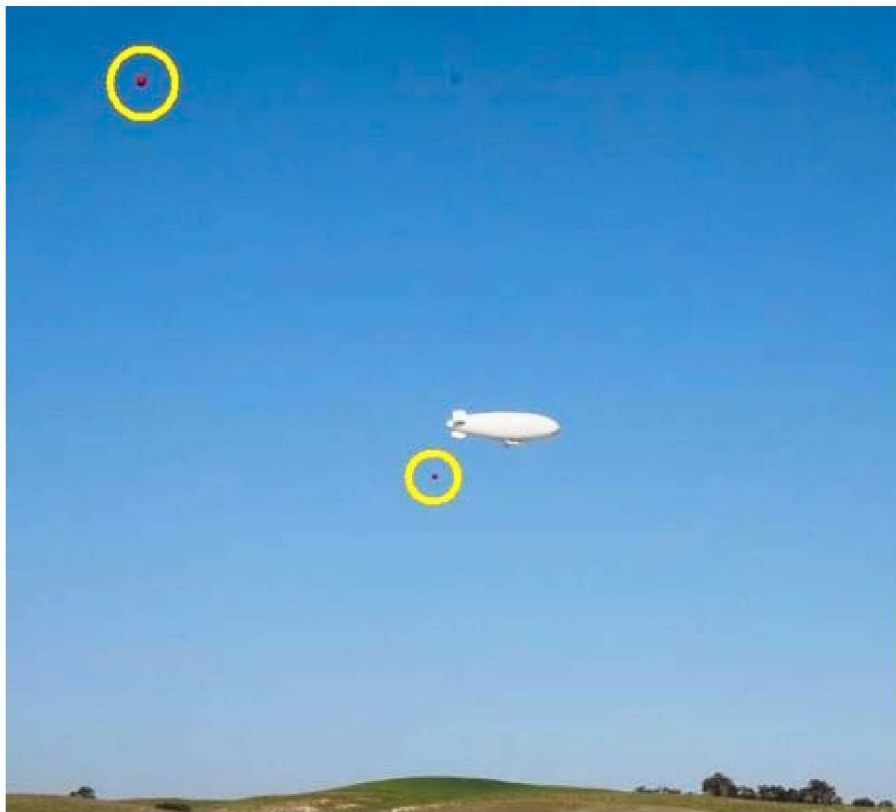
Figure 8. A-170 airship circling tethered balloons
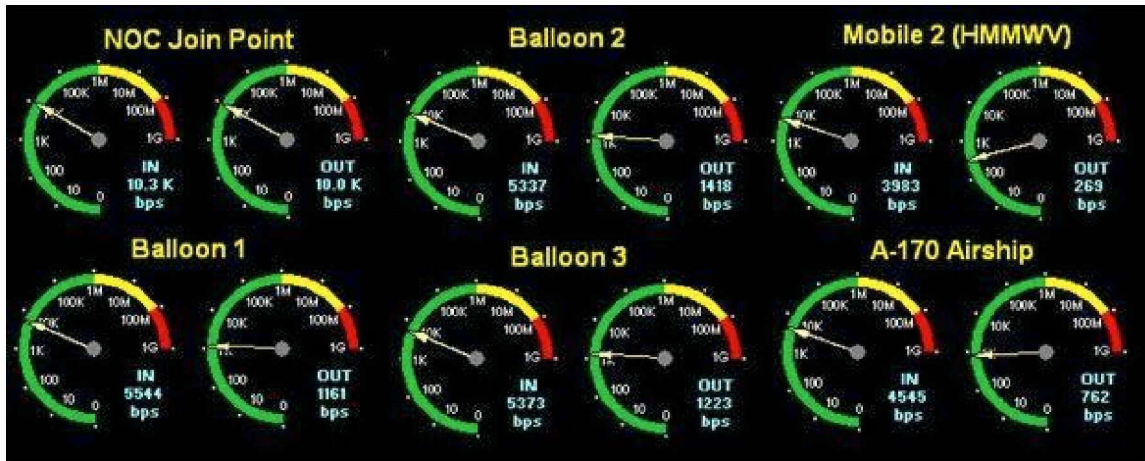
Figure 9. Screen capture of Solar Winds bandwidth gauges during A-170 flight. At the time of this capture, all nodes were up and streaming excellent video.

Despite the increase traffic load, the video received from the balloons was more stable and the mobile ground nodes located in the HMMWVs (Mobile 2 in Fig. 9) had much improved connectivity to the mesh. The self-healing nature of the mesh was not fully flexed in these experiments though due to the relatively small number of nodes. In order to more fully test this aspect of the mesh, many more nodes need to be interspersed throughout the mesh. In this way, packets will have a variety of routes to travel from distant end to distant end. In the more linear set up of this experiment with so few nodes, it is difficult to discern if route selection was a function of optimization or mere availability.

D.   TNT-1 FINDINGS

The results from TNT-1 indicated that the mesh network components required considerably more investigation before a reliable demonstration network could be fielded. The payloads for the tethered balloons, as described earlier, were fitted with Dell X300 notebook computers. While they

are extremely lightweight and capable, they are not rugged and are certainly not intended to be dangled at 1000 feet AGL or exposed to the elements for any extended periods of time. Even with extended six hour batteries, this configuration lacked the long lasting on-station time desired for persistent surveillance nodes.

The payload in the Tern was configured somewhat differently. The computer used was a Toshiba Libretto notebook. Less capable than the Dell X300, it was chosen solely based on the combination of its physical dimensions (Fig. 10) and its ability to meet minimal computing requirements for running OLSR 4.7 and the SA Agent software.

Figure 10.   Tern payload using Toshiba Libretto during
TNT-1

A major problem with the Tern payload was its near inability to operate simultaneously while the Tern's engine started up. This was discovered when although a pre-experiment check of the payload was satisfactory, it failed to connect to the network once the Tern was powered up and

taxied down the runway. It is strongly believed that significant vibrations created by the Tern when operating on the deck disrupted the spinning magnetic disk drive in the Libretto causing it to consistently fail.

The use of laptops as networking devices, particularly as the network join point, is less than an optimal solution at best. While their use in TNT-1 was effective in accomplishing stated test objectives which produced valuable data, they are simply not suited for use in an actual tactical environment. Their size, weight, power consumption, overhead (eg. embedded keyboards and monitors which serve no use when unattended) and susceptibility to vibration relegate laptops to merely an interim role on the route to a more appropriate payload solution.

The experiment was unable to determine the true value of the Rajant BreadCrumbs. The devices were not simple network management protocol (SNMP) enabled and so their performance was not captured by network monitoring tools in the TOC although Rajant does provide its own GUI which lends some insight into the health of the network in terms of which links are active. Furthermore, while all TNT network devices are assigned static IP addresses, BreadCrumbs devices have their IP addresses assigned dynamically. While this is a sensible approach for production system, it made integrating BreadCrumbs into the experimental TNT network more challenging.

The findings of TNT-1 indicated that a more suitable payload would have to be flown in future experiments. The TNT-2 experiments would provide the opportunity to field a new payload architecture to test a compact, lightweight

design and how it would support required application flows and mesh connectivity in harsh operating environments.

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III. IMPLEMENTING AN IMPROVED PAYLOAD

While the implementation of the payload nodes in TNT-1 met operational requirement in the case of the tethered balloons, the success of the design was questionable when implemented in the Tern UAV. Even with the balloon payloads, it was clear that the current solution would have to be modified in order to perform in a production environment. While the original TNT payloads were at least functional and allowed for data collection and the ability to execute test scenarios, it was clear that a new implementation was required and the logical choice was to base an improved design on the PC/104 standard for embedded PC architecture.

A.   HARDWARE

1.   Single Board Computer

Embedded computers are used in a variety of applications ranging from information kiosks, medical equipment and testing devices to vending and automated teller machines. They are used when space and power constraints drive the hardware architecture. The PC/104 standard arose from the need for a standard for a compact implementation of the PC bus satisfying reduced space (3.6 inches by 3.8 inches) and power constraints (1-2 watts) without sacrificing full hardware and software compatibility afforded by currently available PC bus standards. The PC/104 architecture offers full hardware and software compatibility with the PC bus, but in compact stackable units[6].

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[6] PC/104.org, "The Need for an Embedded PC Standard," 10 Mar 2005,

The single board computer (SBC), or embedded PC, chosen for the improved payload was the PCM-9373, manufactured by Advantech (Fig. 11). This device has a CPU with a 1G processor, 128KB L1 cache memory and supports a number of I/O interfaces such as EIDE, RS-232, and USB as well as 802.3 100 Base-T Fast Ethernet compatibility[7]. This set up would provide nearly equivalent computing power to the Dell X300 series laptops used for the tethered balloons and much greater capacity than the Toshiba Libretto used in the Tern. The drawback is that the PCM-9373 is an implementation of 16 bit architecture. This would limit the type of wireless adaptors that could be used in the payloads to simple 802.11b devices vice the 802.11a/b/g combo cards used in the past. Since the TNT-2 experiment plan called only for testing the mesh using only 802.11b, this architecture would suffice.
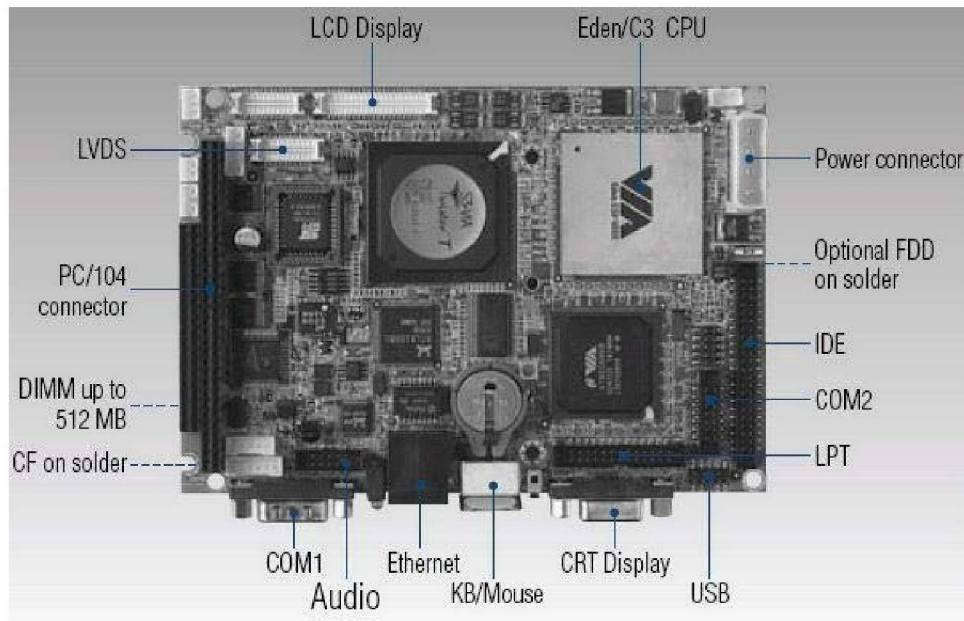

Figure 11.   PCM-9373[8]

<http://www.pc104.org/technology/>.

   [7] Advantech, "PCM-9373 User Manual," 10 Feb 2005.
<http://partner.advantech.com.tw/epartner/Files/Temp/PCM-9373_Manual-ed-1.pdf>

   [8] Ibid

2. Compact Flash Memory

The use of spinning storage media such as common magnetic hard disk drives would be discontinued in the new implementation. Vibrations from the operation of the Tern interrupted and severely degraded the ability of the Libretto notebook to perform during TNT-1. While the balloon nodes did not face the same environmental challenges, stiff winds at 1000 feet AGL would rattle the payload enclosure and it would be a matter of time before the Dell X300 hard disks would fail under operational conditions. For the sake of "ruggedizing" the balloon nodes, their spinning disk drives would be also be discontinued.

Compact flash would serve as the alternative non-volatile storage media. Compact flash cards are small removable mass storage devices designed with flash technology, a non-volatile storage media that can retain data indefinitely without need for a battery. Compact flash cards are solid state; the absence of moving parts not only provides protection against vibration but also increases ruggedness and reliability when compared to magnetic disk drives. A further advantage is that compact flash cards consume only five percent of the power required by other small disk drives[9].

There are a number of vendors that produce compact flash cards. The choices for the TNT-2 payloads at first were 1GB cards by Lexar and SanDisk. Lexar cards were preferred because they are manufactured with write acceleration rated at 80X, the sustained write speed

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[9] Compact Flash Association, "Information About Compact Flash," 7 Mar 2005. <http://compactflash.org/info/cfinfo.htm>

measure analogous to the rating used by CD and DVD drive manufacturers. Later, 2GB cards would be implemented to accommodate installation of the full version of Windows XP Professional.

3. Wireless Network Card and Transmission Media

Due to the 16 bit architecture of the PCM-9373, the Proxim ORiNOCO 802.11a/b/g ComboCards used in TNT-1 would have to be replaced with older Proxim ORiNOCO Gold cards which are only 802.11b capable. While it is not generally preferable to reduce the capabilities of a system, the hardware constraint mandated the move. However, the TNT-2 experiment plans accommodated such a shift as 802.11a/g would not be used. Additionally, 802.11b was the frequency standard used predominantly during previous STAN and TNT experiments so the lost capabilities would hardly be missed.

The 802.11b wireless network adaptor would have to be amplified though in order to extend the range of the 802.11b cards from approximately 100 meters to 1-2 kilometers. This was done with one watt amplifiers which had been used previously in the balloon and Tern payloads. During static test at NPS, these amplifiers enabled connectivity at a range better than 2 kilometers.

In addition to the 802.11b adaptor and its amplifier, the balloons would also be enabled, as they were previously, with GPS receivers and 900MHz radios manufactured by FreeWave Technologies, Inc., which would relay GPS data from the nodes to the join point which would then parse the information for geo-location purposes.

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These radios interfaced through RS-232 ports and provide reliable data transmission at extended range.

B.   SOFTWARE

1.   Windows XP Embedded versus XP Professional

Windows XP Professional with Service Pack 2 is the choice of operating system for TNT mesh network nodes. The full version of Windows XP Professional requires just over 1GB of non-volatile memory for installation.   This initially prevented use of the full version of XP as all of the compact flash cards had 1GB of storage. Many hours were spent attempting to create a Windows XP embedded version perfectly suited to the needs of TNT.   All components considered non-essential were stripped off. The vendor of the single board computers also provided its own version of embedded XP.

These versions lacked some of the required component functionality however.   While they supported wireless networking in an ad hoc environment, a network bridge could not be created with the software between the wireless network adapter and the wired Ethernet port.   This functionality was required to support video streaming using a Pelco digitizer, a device that has its own IP address.

Compact flash cards with more memory were implementd and the full versions of Windows XP Professional were installed.   The software bridge still failed to initialize indicating an incompatibility in the hardware configuration to support network bridging.

2. TNT Specific Applications

The scenarios developed for TNT along with the network monitoring requirements necessitate several special software applications be loaded and running during experiments. All of these applications run on standard Wintel computers. The required software in addition to the operating system includes:

a. OLSR Switch

The OLSR Switch program provides the mesh routing algorithm behind the wireless communications in TNT. It provides a GUI for selecting the node's interface and viewing its routing tables and neighbor lists (fig 12). The software is readily available for download from many sites including www.olsr.org. The software is frequently updated; during TNT-2 OLSR version 4.8 was used.
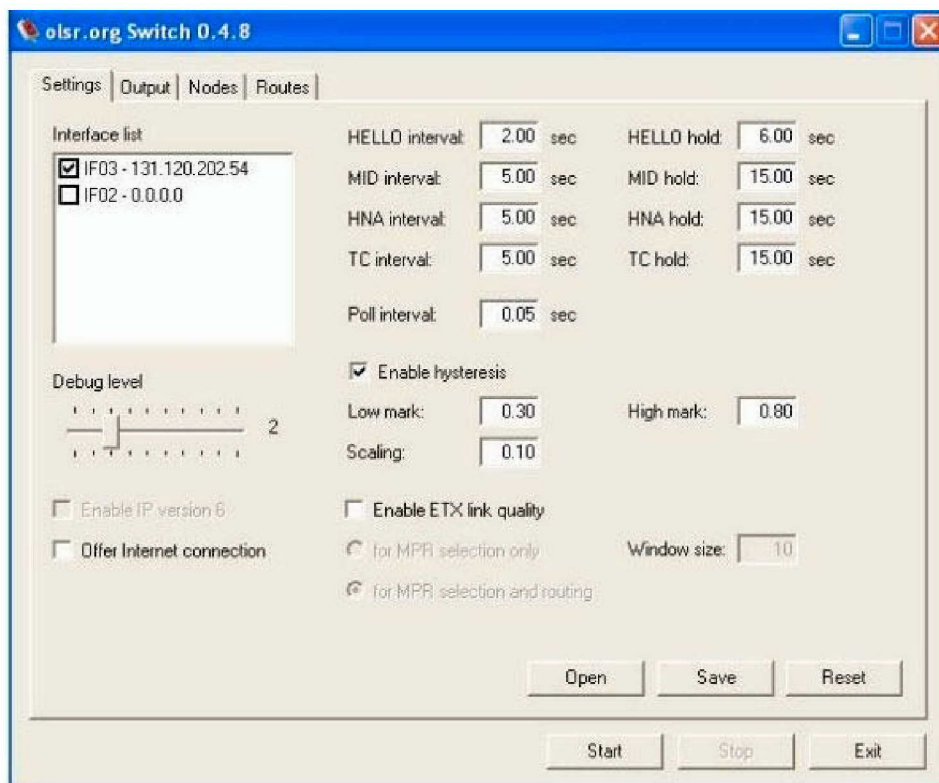
Figure 12.   OLSR Switch ver 4.8

b. SA Agent

The SA Agent application was developed at NPS in conjunction with early STAN experiments, employing an incremental spiral development approach which produces an improved application for each successive quarterly TNT experiment. The software actually consists of a suite of tools accessed through a client-server interface which provide users with chat, geo-location, network status, video streams and alerts in a Macromedia Flash environment (Fig. 13). The SA Agent application is critical to the accomplishment of TNT objectives, providing a network traffic load and a basket of tools for progressing through various scenarios. More importantly, SA Agent provides a glimpse into how shared situational awareness can be implemented and managed which is the ultimate goal of the TNT project.

Figure 13.   Situational Awareness (SA) Agent

c. GPS Marker

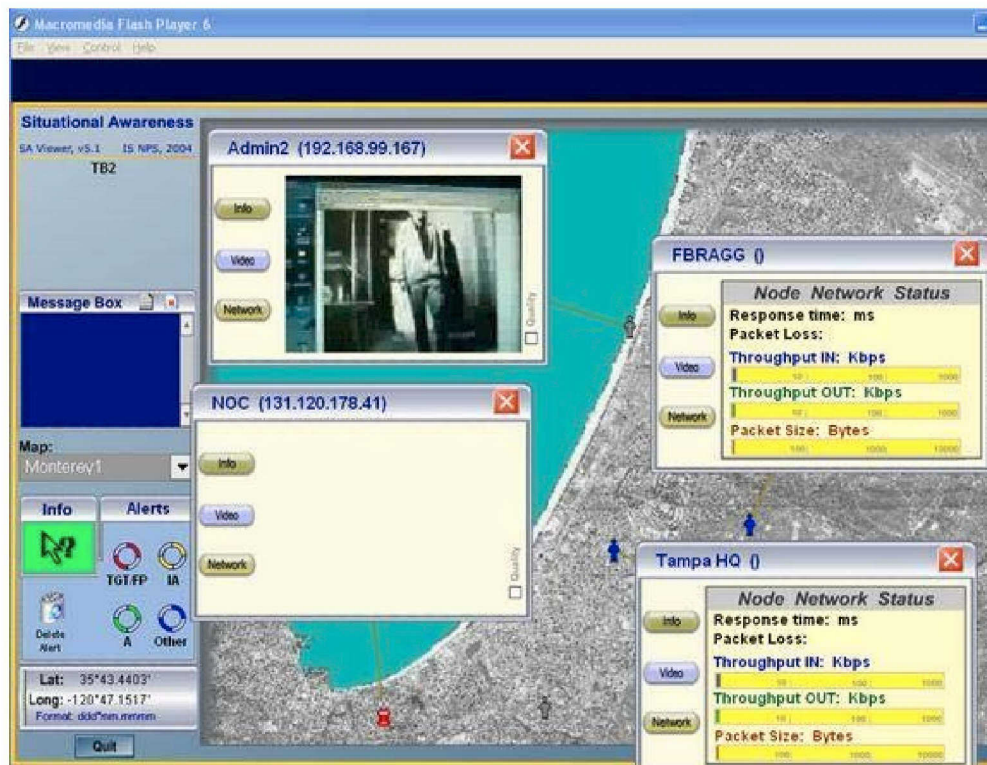GPS Marker is an application running a Visual Basic script used for geo-location. It is necessary because although each node receives a GPS feed there is no unique identifier associated with each GPS receiver. Once GPS information has been relayed back to the SA Agent server, the server needs some way to identify which node's coordinates it has received. GPS Marker accomplishes this by adding a unique identifier to the GPS data stream and then routing the data to the appropriate port for transmission via FreeWave radio. At the receive end, a node running GPS Parser receives the data streams and is able to then correlate GPS data to the appropriate nodes.

d. Macromedia Flash Communication Server

The major source of traffic load for data collection on network behavior is streaming video. This also serves to facilitate the operational aspect of TNT by providing simulated reconnaissance and surveillance video to the TOC which can then use the information to drive event driven scenarios. In previous STAN and TNT experiments, payloads were equipped with a Pelco digitizer for the video feed. The Pelco set had its own IP address which then had to be bridged through software in the mesh node to create a link between the captured video and the wireless pathway that would carry this traffic. The PCM-9373's inability to support software bridging necessitated the introduction of an alternate solution. The alternative involved installing Flash Communication Server on each node which allowed for the broadcast of video and audio streams from simple cameras and microphones connected to the nodes.

e.   *Ixia Performance Endpoint*

        Ixia produces IP network monitoring and testing
tools.   Their tools, such as Q-Check and IxChariot, are
used throughout TNT to capture performance measures such as
data rate, latency and throughput while also offering tools
to shape predictions on system performance under expected
operational conditions[10].   These tools require performance
endpoint agents installed on the devices to be tested.   The
endpoint agents collect information on their device's
network transactions and then transmit the data to the
computer running the test.

C.   FIELDING THE PAYLOAD

        The experimental phase of TNT-2 provided several
scenarios spread over the course of a week at Camp Roberts
near Paso Robles, CA, to flex the mesh networking
architecture in place and test the capabilities of the
improved airborne node payloads in an operational context
outside of the laboratory.   The hardware components were
fit together in a compact plastic casing for the tethered
balloons and mounted directly to the underside of the nose
section of the Tern (Fig. 14 and 15).

        The use of compact flash memory provided two
takeaways.   First, although the Lexar cards were advertised
with 80X write acceleration, the payloads they were in
booted extremely slowly while the SanDisk compact flash
units booted amazingly quickly (approximately thirty

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[10] Ixia, "Performance Testing: IxChariot," 18 Mar 2005.
<http://www.ixiacom.com/products/performance_applications/>

seconds or less). There was no other discernable difference between the two brands.

Figure 14.   Eugene Bourakov reels in an enclosed balloon payload prior to deployment at the TOC at Camp Roberts
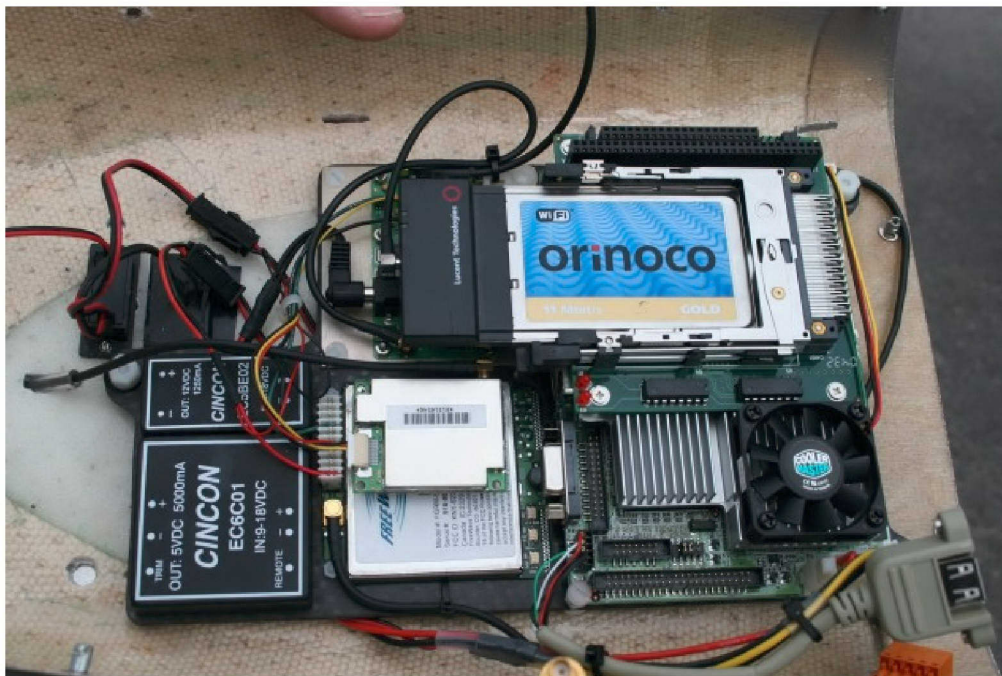

Figure 15.   Tern UAV payload

The second issue with the compact flash cards was the way that they fit into the PCM-9373. The design of the

board required that the system's RAM be lifted up in order to slide the card into place. Not only was this placement inconvenient, but it also caused the card to rattle loose inside the Tern due to vibration. This issue however was easily alleviated by placing a shim over the RAM to hold it in place and prevent any vibrations from shaking the card loose.

The disadvantage of the payload configuration was a lack of a monitor and I/O device. The devices were configured to begin running the streaming video server, GPS Marker and OLSR immediately following the boot sequence. However, an operator had to log onto the payloads using Microsoft Remote Desktop to select the OLSR interface and start it, as well as to initiate SA Agent in order for the payload to provide updates to the server. This could not be done sans connectivity however which made troubleshooting a timely, tedious and painstaking endeavor.

When balloons payloads failed, they had to be recovered in order to troubleshoot. Likewise, when the Tern payload failed, the nose section had to be removed to access the payload. However, these difficulties were not new nor were they the result of the redesign but simply a matter of the nature of their usage. However, once the payloads were physically accessible, another device was required to troubleshoot remotely (if connectivity was available) or else they had to be returned to the TOC for diagnosis with external displays and input devices.

The improved payloads did surpass the reliability of their predecessors in terms of on-station time. The battery packs used to power the payloads provided over eight hours of battery life under operational conditions.

This result means that a balloon payload could be raised at daybreak and operate until the end of the day's data collection without need for a battery change. Similarly, the Tern payload could easily operate longer than the Tern's maximum operational endurance of five hours.

By the completion of TNT-2, the airborne payloads had proven to operate effectively and their architecture could support accomplishment of all major requirements. When passing video, they achieved data rates comparable to those achieved in previous experiments. However, connectivity between the airborne nodes was inconsistent. While the payload that operated at the physical location of Balloon 1 seemed to be fairly reliable, the others were up and down. The Tern performed similarly. It passed video at distance of approximately 1.5km, but was more often intermittent.

These shortfalls however are likely due to the decision to operate the mesh network on top of an 802.11b foundation. The Tern had the added challenge of rapid mobility. It is likely that 802.11b lacks the robust reliability to form the foundation for a reliable and robust mobile mesh MANET for military operations.

IV. FUTURE ITERATIONS

A.   HARDWARE UPGRADES

The Advantech PCM-9373s should be replaced with single board computers which support 32 bit architecture. These are available under the PC/104-Plus standard. The drawbacks imposed by the 16 bit architecture of the PCM-9373 seemed to be the cause for most of the problems during TNT-2. A 32 bit board would support using newer network adaptors providing the flexibility to conduct tests using 802.11g instead of being confined to only using 802.11b. Also, this would provide the opportunity to test commercially available alternatives to OLSR such as that employed with the MeshNetworks/Mesh4G WMC 6300 card.

Another upgrade would be to implement SanDisk 2GB compact flash cards in all the embedded nodes. The boot time for computers using these cards (even thought they had a full version of Windows XP Professional) was about thirty seconds or less compared to the Lexar compact flash cards which seemed to perform very sluggishly. These cards would be a cost effective way to quickly improve performance. Additionally, it is invaluable to have the ability to quickly reboot a node when troubleshooting away from the TOC.

B.   SOFTWARE UPGRADES

While using the full version of Windows XP Professional has the advantage of not potentially missing components that are required or may be required in the future, it still stands to reason that a stripped down

version of embedded Windows XP would be preferable and improve boot time and possible system memory usage.

However, given the fact that there were no failures during TNT-2 that could be attributed directly to the operating system, it seems that limited resources could be devoted elsewhere to provide a more immediate impact.

Prior to TNT-3, careful attention should be paid to the current release of OLSR. There were significant changes between OLSR version 4.8 and version 4.7 which was used in TNT-1. Although it is unlikely that this was cause for any of the intermittent connectivity experienced during TNT-2, prudence dictates that the latest OLSR versions be studied thoroughly and tested in the NPS GIGA Lab prior to field experimentation at Camp Roberts.

C.   IMPROVING CONNECTIVITY

While the focus of this thesis has been to lay the hardware foundation for building airborne mobile mesh network nodes, the mixed results of TNT-1 and TNT-2 indicate that the network links themselves need further study. Connectivity via 802.11 needs to be examined and alternative Layer 1 and 2 solutions considered.

The standards and technology behind 802.11 and Wi-Fi were not developed with high speed mobility in a tactical environment in mind. The standards were developed to do what they do best: provide broadband wireless connectivity in a stable, confined environment. The ubiquity of Wi-Fi equipment makes it the natural choice for the earliest implementations of a mesh MANET during past iterations of STAN and TNT. However, the limitations of 802.11 have been reached and it is time to seek alternative solutions.

In the case that TNT continues to use 802.11 as the underlying network framework, further study into mesh routing protocols will be a must in order to optimize the effectiveness of the links and improve the ability to merge traffic from the mesh to the wired network through the join point.

D.   RECOMMENDATIONS FOR FOLLOW ON RESEARCH

1.   Explore Commercial Alternatives to OLSR

Several commercial vendors supply alternative mesh networking solutions that rely on proprietary algorithms rather than open standards such as OLSR (which has been used predominantly in the TNT and STAN experiments) and AODV. These solutions vary in cost and implementation but typically they offer some sort of wireless network adaptor for their system and a variety of accompanying wireless bridging and routing equipment.

MeshNetworks offers a line of products which would fit nicely into the TNT design (Mesh4G sells a commercial line of the products). They use wireless modem cards which can be used in any portable device's PCMCIA slot. These cards have a range of over 1 kilometer. MeshNetworks also sells the join point solution, an Integrated Access Point (IAP) which is controlled by a Mobile Internet Switch Controller (MISC) and plugs into the existing wired network (Fig. 16). Additionally, MeshNetworks products have a geo-location capability built-in[11]. The range of the radios coupled with the full mesh product line offered makes this worthy of further study.

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[11] Mesh4G, "M4 Mobile Broadband Network Products," 15 Mar 2005, <http://www.nowwireless.com/mesh4g/M4products.htm>.
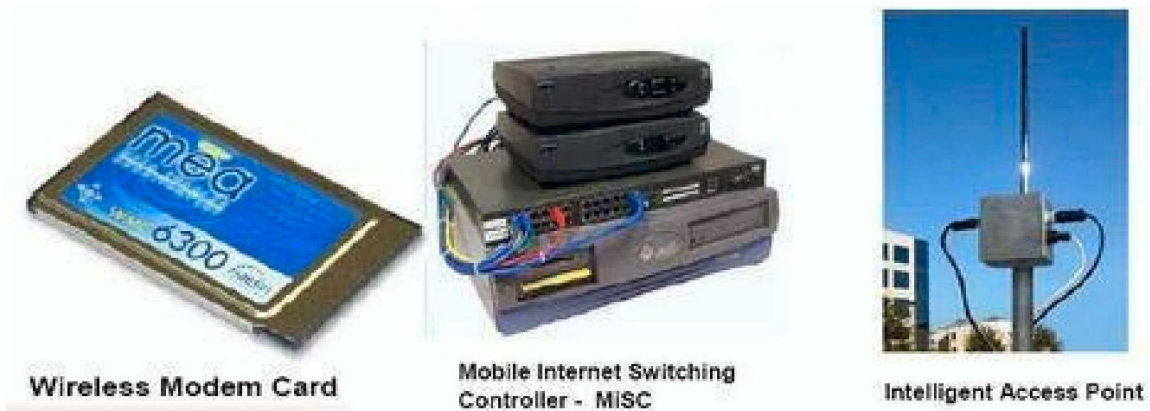
Figure 16.   Commercially available mesh networking
solutions by MeshNetworks/Mesh4G[12]

Strix Systems offers another alternative solution. Their flexible Access One system (Fig. 17) is composed of modular antennas that can support an array of wireless technologies. Nodes can simply plug into the units which "self tune" to discovery optimal pathways for traffic. Strix Systems also boasts other mesh advantages such as the ability to rapidly deploy and self-heal[13].

Figure 17.   Strix Systems Access/One Network[14]

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[12] Ibid

[13] Strix Systems, "Access/One Network," 20 Mar 2005 <http://www.strixsystems.com/products/>

[14] Ibid

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2. Implementing an 802.16/WiMax Alternative

The groundwork for 802.16 within the TNT architecture has been laid. The 802.16 OFDM backbone for the TNT network stretches from CIRPAS-Marina, to the GIGA Lab at NPS to the TOC at Camp Roberts and points in between. These links are robust, reliable, long range and provide very high data rates. Research should begin into the possibility of implementing 802.16 in the airborne nodes.

3. Use of Multi-Radio Technology

One problem that is pervasive for all wireless mesh networks regardless of the routing algorithm choice is that they are confined to a shared radio channel. As the network scales up and as mobile nodes frequently enter and leave the mesh routing tables must be updated and the number of control messages vastly increase limiting the number of useful bits (from the end user's perspective) that can be transmitted.

Multi-radio systems are an attempt to work around this mesh network shortcoming. These systems use separate radios for uplink and control. However, this comes at a cost in terms of increased complexity and power and amplification requirements. Still, these systems deserve further attention.

4. Scalability

Throughout the TNT experiments to date little emphasis has been placed on scalability. When researching mesh networks, two ideas emerge. The first is that as many nodes are added to the mesh, the network actually becomes much more robust as new routes are introduced into the

network. The second notion is that as the mesh scales up, the network becomes crippled by the increasing control message traffic as routes are constantly changing and route tables try to keep pace. So far, most experiments in TNT scenarios deal with a handful of nodes, typically around a half dozen. Research should be conducted into the scalability issue, whether physically or through modeling, to determine the expected characteristics of mesh MANET performance on the battlefield where dozens if not hundreds of nodes or more would be meshed.

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